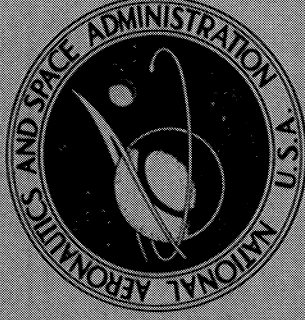


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**PRELIMINARY RESULTS OF
COMPRESSION TESTS ON
CYLINDERS WITH ECCENTRIC
LONGITUDINAL STIFFENERS**

*by Michael F. Card
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SUMMARY

Preliminary results from an experimental study of the effect of stiffener eccentricity on the buckling load for cylinders loaded in compression are reported. The results of buckling tests conducted on four integrally stiffened cylinders and two Z-stiffened cylinders are presented. The tests reveal that an externally stiffened cylinder may carry over twice the load sustained by its internally stiffened counterpart. Available shell buckling solutions have suggested this phenomenon but are not adequate for predicting the experimental results because of differences between the boundary conditions at the ends of the cylinders considered in the solutions and those of the experimental cylinders discussed herein.

INTRODUCTION

It has been recognized that eccentricities (one-sidedness) in stiffening elements can influence predictions of the buckling strength of stiffened shells (refs. 1 to 4). For compressive loading of stiffened cylindrical shells that buckle asymmetrically, theoretical analysis suggests that the longitudinal stiffening elements (stringers) should be located on the external surface of the shell for maximum effectiveness in increasing compressive buckling strength. The magnitudes of the eccentricity effects may be quite large. Reference 4 suggests that a cylinder with symmetric longitudinal stiffening may carry as much as three times the load carried by the corresponding internally stiffened structure. Unfortunately, little, if any, experimental evidence can be found to verify the trends suggested by theory.

The purpose of the present report is to present some preliminary results of an experimental study of the effect of stiffener eccentricity on the compressive strength of longitudinally stiffened cylinders. Tests of six stiffened cylinders, representing three cylinder configurations with either internal or external stiffeners, have been completed and are reported herein.

SYMBOLS

The units used for the physical quantities in this report are given both in the U.S. customary units and in the International System of Units, SI (ref. 5). An appendix is included for the purpose of explaining the relationships between these two systems of units.

A	cross-sectional area of cylinder wall, in. ² (cm ²)
l	length of cylinder, in. (cm)
n	number of circumferential waves in buckle pattern
P _{max}	applied axial load at cylinder failure, kips (kN)
R	radius of cylinder to skin midplane, in. (cm)
t	thickness of cylinder skin, in. (cm)
ε	average compressive strain at strain-gage station experiencing maximum strain
η	ratio of the compressive buckling stress of an externally stiffened cylinder to the compressive buckling stress of its internally stiffened counterpart
σ	average compressive stress in cylinder, ksi (MN/m ²)
σ _{max}	average compressive stress in cylinder at failure, ksi (MN/m ²)

SPECIMENS AND PROCEDURES

Specimens

Two types of longitudinal stiffening were employed on the test cylinders of this investigation: integral stiffening and Z-stiffening. For each type of stiffening, buckling data were obtained for cylinders designed with identical cross sections and varying lengths. Corresponding to each length, two cylinders, one with external stiffening, the other with internal stiffening, were tested. All the specimens were designed with closely spaced stiffeners to preclude local buckling of the cylinder skin.

The integrally stiffened cylinders were machined from 3/8-inch (0.95-cm) aluminum plate. Four integrally stiffened cylinders representing two "internal-external" configurations were tested and are reported herein.

The Z-stiffened cylinder designs were virtually identical to certain test specimens discussed in reference 6, the difference being that in the present

test specimens, the Z-stiffeners were located on the external rather than internal surface. At this time only one Z-stiffened cylinder of a proposed series of four externally stiffened cylinders has been tested. The data from the comparable internally stiffened cylinder taken from reference 6 are included in this report for comparative purposes.

Construction details of the test specimens are given in figure 1 and table I. For the integrally stiffened cylinders, the dimensions were obtained by careful measurement. The cylinder skin thickness t given in the table is the average of a large number of micrometer measurements. The scatter in individual thickness measurements was less than ± 8 percent of the tabulated value. For the Z-stiffened cylinders, all dimensions are nominal except the area of the cylinder cross section A which was determined by weighing, and the skin thicknesses, which were obtained from micrometer measurements.

Procedure

The cylinders were loaded in compression in the 1,200,000-pound-capacity universal static testing machine at the Langley Research Center. The ends of the cylinders were ground flat and parallel prior to testing. The cylinders were carefully aligned in the testing machine to insure uniform bearing between the ends of the cylinders and the platens of the testing machine. Circularity of the cylinders was maintained during the tests with the use of aluminum bulkheads at each end of the cylinders.

Twelve resistance-wire strain gages with a 6-inch (15.2-cm) gage length were mounted in back-to-back pairs on the cylinder skin and stringers to check stress distribution and to detect buckling. As a further indication of the structural behavior of the specimens, the overall shortening of the distance between the testing-machine platens was measured with the use of resistance-wire strain gages mounted on small cantilever beams whose deflection was equal to the shortening of the distance between the platens. The strain and shortening measurements were recorded during the test at a virtually continuous rate on the Langley central digital data recording system.

TEST RESULTS

Stress Distribution

Stress-strain curves derived from the strain-gage data for each of the test cylinders are presented in figure 2. The strain plotted is that measured at the station experiencing the maximum strain during the test. The value of strain corresponds to the average of data from a pair of back-to-back gages mounted on either stiffeners or skin. The strain distribution in the cylinders was quite uniform for all tests. Individual strain-gage readings at loads near buckling differed at most by 10 percent of the plotted values. Strains measured in back-to-back gages prior to buckling differed by about $\pm 1\frac{1}{2}$ percent of their average value.

Examination of the strain data indicated no local buckling of the cylinder skin prior to failure. The data also indicate that for all cylinders except cylinder 4, the buckling load and maximum load could be considered to be identical. In cylinder 4, strain reversal was observed to occur at a load about 1 percent less than the maximum load carried by the cylinder.

All the stress-strain curves of figure 2 are linear up to at least 85 percent of the maximum stress carried by the cylinder. The slope of the linear portion of the curves gives values for Young's modulus in reasonable agreement with conventional values of the modulus (ref. 7). Slopes of load-shortening curves derived from the average of cantilever measurements were also in agreement with accepted values for both 2024 T-351 and 7075-T6 aluminum alloys.

Failure

The maximum loads together with the corresponding compressive stresses carried by the cylinders at failure are given in table I. For the externally stiffened cylinders, failure was accompanied by a loud report and the appearance of several diamond-shaped buckles of large amplitude. For the internally stiffened cylinders, failure was a milder phenomenon with similar buckle patterns of smaller amplitude. In general, the buckling patterns for all cylinders were the same as those described in reference 6 with the exception of cylinder 1 which buckled into two tiers of diamond-shaped buckles rather than one. Photographs of the buckled cylinders are shown in figure 3. The number of circumferential waves into which the cylinder buckled n (as defined in ref. 6) is shown in table I.

DISCUSSION OF TEST RESULTS

The maximum loads carried by the stiffened cylinders indicate that locating the longitudinal stiffening of a cylinder on its exterior surface can produce a significant increase in load-carrying ability over the comparable internally stiffened structure. A measure of the structural strength to be gained by external stiffening is the ratio η of the buckling stress of the externally stiffened structure to the buckling stress of its internally stiffened counterpart. The following table summarizes the buckling stress ratios indicated by the test results:

Cylinder	Type of stiffening	R, in. (cm)	l/R	η
1 and 2	Integral	9.55 (24.2)	3.98	2.36
3 and 4	Integral	9.55 (24.2)	2.38	2.02
5 and 6	Z-stiffened	15.80 (40.1)	3.71	1.73

It should be noted that the integrally stiffened cylinders as well as the single Z-stiffened cylinder tested exhibited virtually no postbuckling strength so that for those cylinders the buckling and maximum stresses coincide.

Reference 6, however, indicates that cylinder 6 buckled at a stress (13.7 ksi, 94.4 MN/m²) slightly less than that corresponding to maximum load (see table I).

Plasticity effects may also influence the values of the ratio η shown. Consideration of the maximum stresses occurring in cylinders 1 and 3 gives rise to the possibility of plastic stresses occurring in these cylinders before failure. Reference 7 suggests that 2024-T351 aluminum alloy may have a compressive yield stress less than 38 ksi (262 MN/m²) and hence stresses in cylinders 1 and 3 probably exceeded the proportional limit of the cylinder material.

To make buckling predictions for cylinders of the proportions of those discussed herein, the effects of the boundary conditions at the ends of the cylinders must be considered. At the present time, there are no published compressive buckling solutions for cylinders having boundary conditions other than simple support with the exception of the result obtained for the isotropic cylinder. Conventional analyses for stiffened cylindrical shells (e.g., refs. 6 and 8) are based on orthotropic shell buckling solutions in which the eccentricity of the stiffening elements is ignored. Such analyses are obviously inadequate for predicting the magnitudes of buckling loads obtained by the experiments presented herein. It is apparent that a need exists for theoretical shell buckling solutions for stiffened shells in which the effects of stiffener eccentricity as well as cylinder boundary conditions are taken into account.

CONCLUDING REMARKS

The results of compression tests on six longitudinally stiffened cylinders to determine the effect of stiffener eccentricity on the buckling load of the cylinders have been presented and discussed. The test results indicate that an externally stiffened cylinder can carry over twice the load sustained by its internally stiffened counterpart. Existing theory is inadequate for predicting the buckling loads obtained by experiment.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., June 18, 1964.

APPENDIX

CONVERSION OF U.S. CUSTOMARY UNITS TO SI UNITS

The International System of Units (SI) was adopted by the Eleventh General Conference on Weights and Measures, Paris, October 1960, in Resolution No. 12 (ref. 5). Conversion factors required for units used herein are:

Length: Inches \times 0.0254 = Meters (m)

Area: Square Inches \times 0.00064516 = Square meters (m^2)

Force: kips \times 448.2216 = Newtons (N)

Stress: ksi \times 6894.757 = Newtons per square meter (N/m^2)

Prefixes to indicate multiples of units are:

10^3 kilo (k)

10^{-2} centi (c)

10^6 mega (M)

REFERENCES

1. Van der Neut, A.: The General Instability of Stiffened Cylindrical Shells Under Axial Compression. Rep. S. 314, Nat. Aero. Res. Inst. (Amsterdam), 1947.
2. Baruch, M., and Singer, J.: Effect of Eccentricity of Stiffeners on the General Instability of Stiffened Cylindrical Shells Under Hydrostatic Pressure. Jour. Mech. Eng. Sci., Vol. 5, No. 1, 1963, pp. 23-27.
3. Hedgepeth, John M.: Design of Stiffened Cylinders in Axial Compression. Collected Papers on Instability of Shell Structures - 1962. NASA TN D-1510, 1962, pp. 77-83.
4. Van der Neut, Arie: General Instability of Orthogonally Stiffened Cylindrical Shells, Collected Papers on Instability of Shell Structures - 1962. NASA TN D-1510, 1962, pp. 309-321.
5. Anon.: International System of Units, Resolution No. 12. NASA TT F-200, 1964.
6. Peterson, James P., and Dow, Marvin B.: Compression Tests on Circular Cylinders Stiffened Longitudinally by Closely Spaced Z-Section Stringers. NASA MEMO 2-12-59L, 1959.
7. Anon.: Metallic Materials and Elements for Flight Vehicle Structures. MIL-HDBK-5, U.S. Dept. Defense, Aug. 1962. (Supersedes MIL-HDBK-5, 1961.)
8. Card, Michael F.: Bending Tests of Large-Diameter Stiffened Cylinders Susceptible to General Instability. NASA TN D-2200, 1964.

TABLE I.- DIMENSIONS AND TEST RESULTS FOR CYLINDERS

(a) U.S. Customary Units

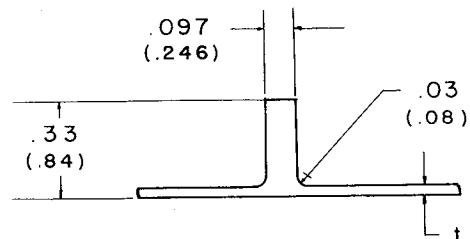
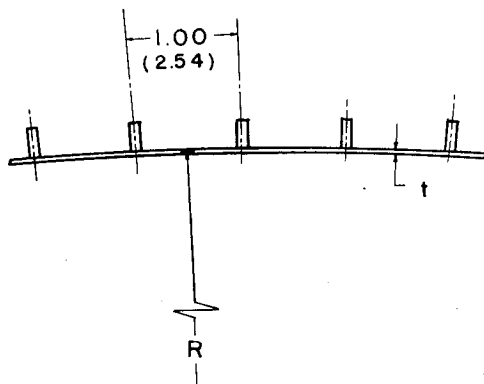
Cylinder	Aluminum alloy	Type of stiffener	Stiffener location	t, in.	l, in.	R, in.	A, in. ²	P _{max} , kips	σ _{max} , ksi	n
1	2024-T351	Integral	External	0.0283	38.00	9.55	3.69	112.6	30.5	6
2	2024-T351	Integral	Internal	0.0277	38.00	9.55	3.72	48.0	12.9	6
3	2024-T351	Integral	External	0.0275	23.75	9.55	3.70	127.2	34.4	7
4	2024-T351	Integral	Internal	0.0280	23.75	9.55	3.63	61.6	17.0	6
5	7075-T6	Z	External	0.0410	59.00	15.80	7.15	169.6	23.7	5
6*	7075-T6	Z	Internal	0.0401	59.00	15.80	7.25	116.0	16.0	6

*Data taken from reference 6.

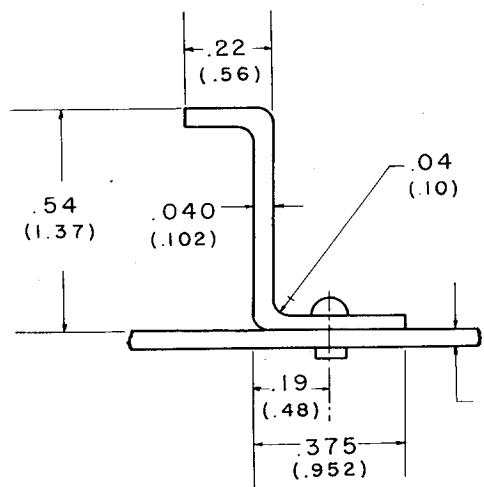
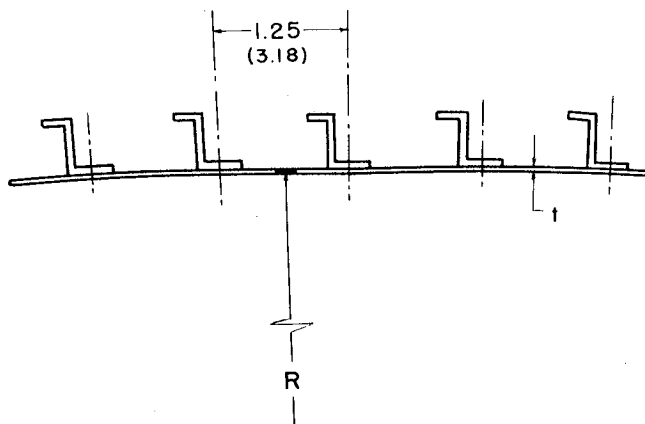
(b) International System of Units

Cylinder	Aluminum alloy	Type of stiffener	Stiffener location	t, cm	l, cm	R, cm	A, cm ²	P _{max} , kN	σ _{max} , MN/m ²	n
1	2024-T351	Integral	External	0.0719	96.5	24.26	23.8	500	210	6
2	2024-T351	Integral	Internal	0.0704	96.5	24.26	24.0	214	89	6
3	2024-T351	Integral	External	0.0699	60.3	24.26	23.9	566	237	7
4	2024-T351	Integral	Internal	0.0711	60.3	24.26	23.4	274	117	6
5	7075-T6	Z	External	0.1041	149.9	40.13	46.1	754	163	5
6*	7075-T6	Z	Internal	0.1019	149.9	40.13	46.8	516	110	6

*Data taken from reference 6.



(a) Integrally stiffened cylinders.



(b) Z-stiffened cylinder.

Figure 1.- Wall geometry of cylinders. Dimensions are in inches. (Parenthetical dimensions in cm.)

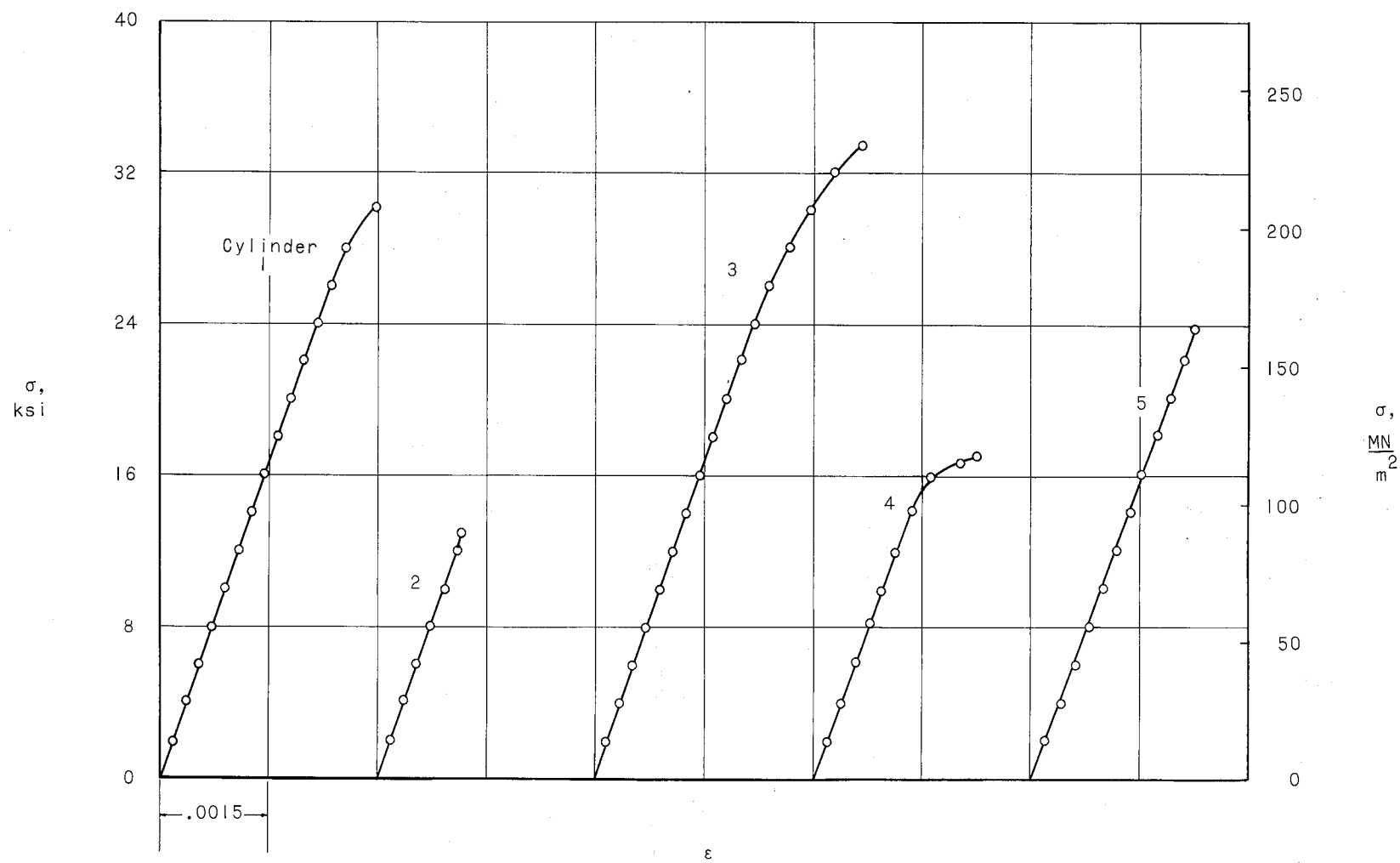
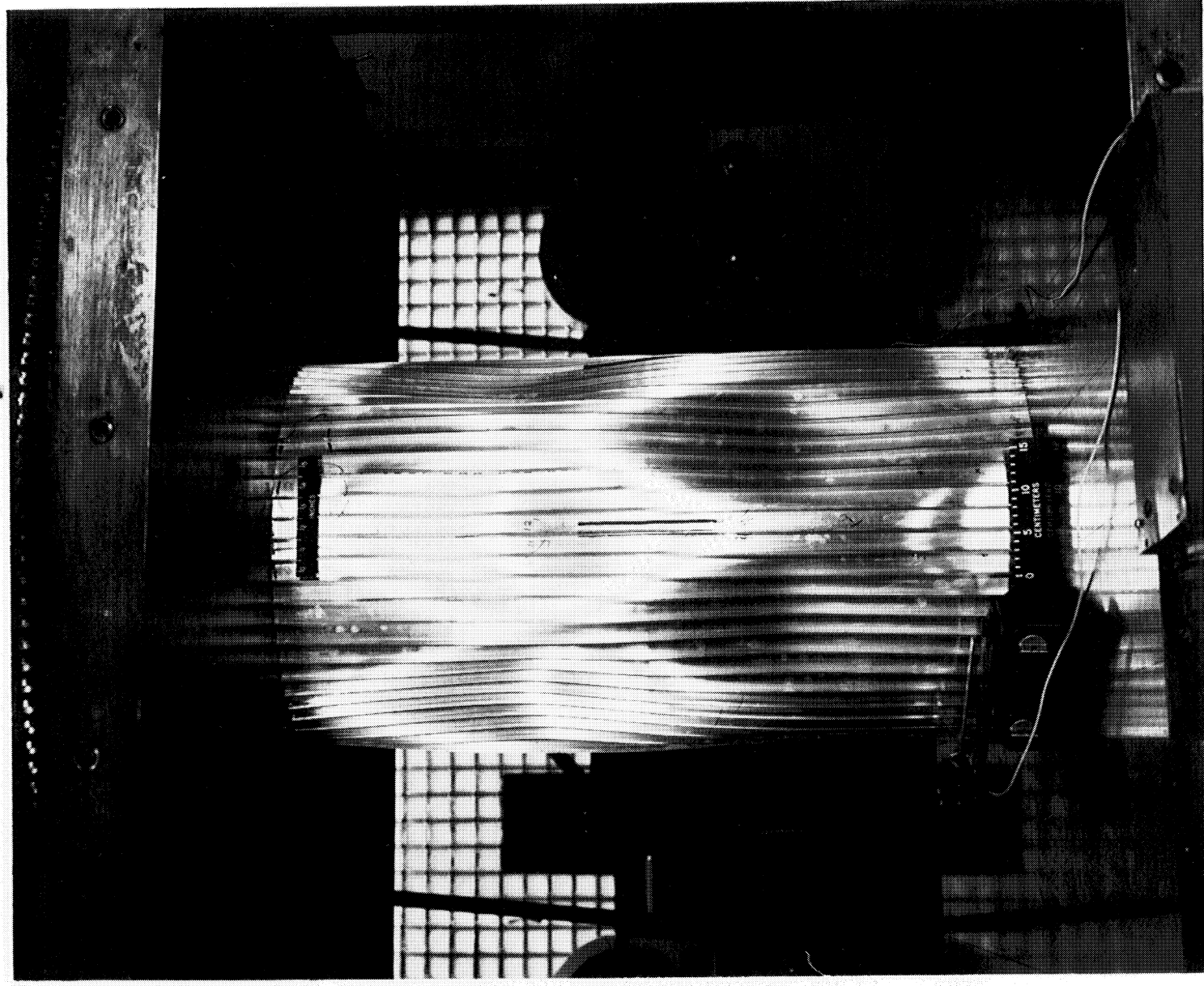


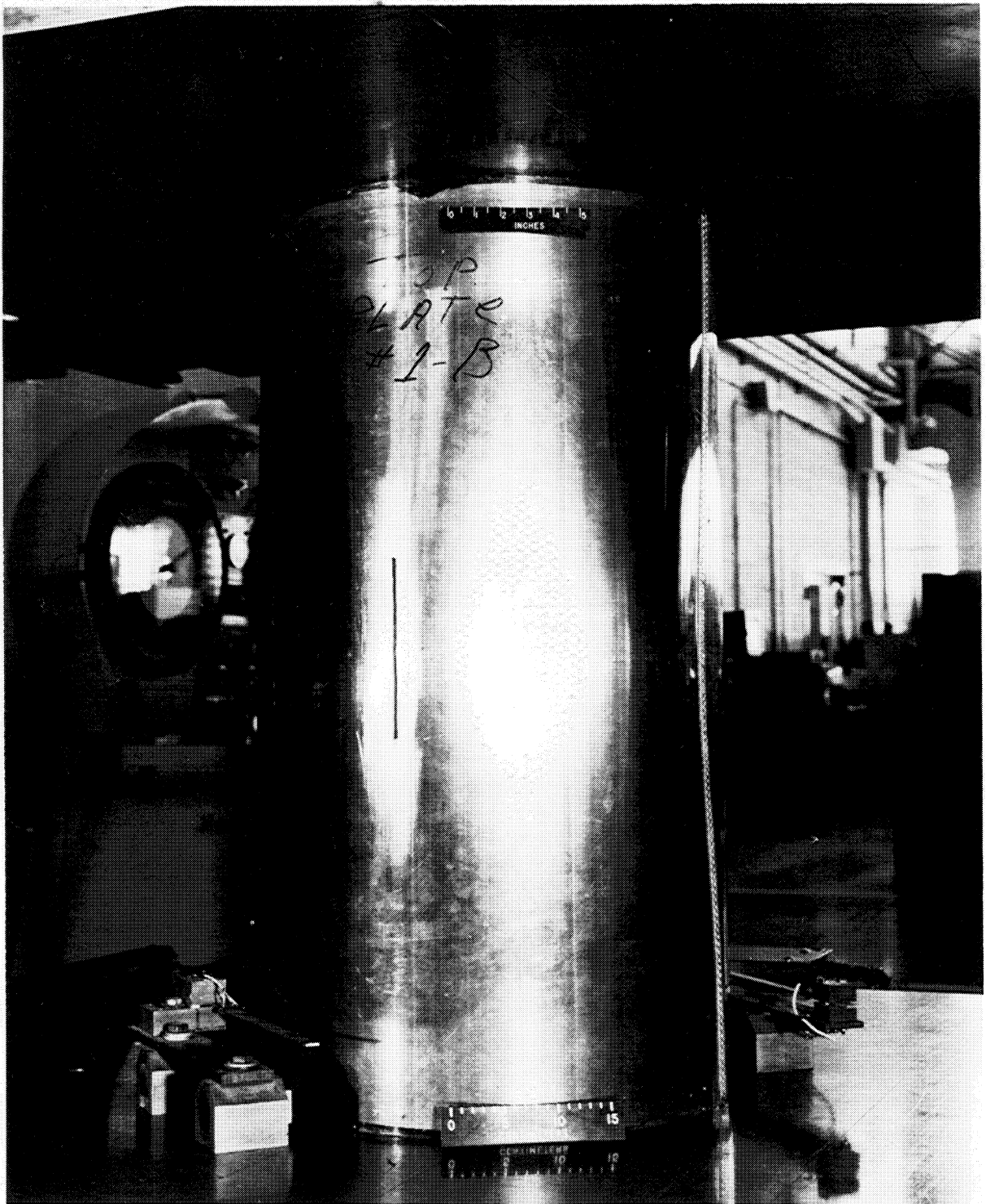
Figure 2.- Cylinder stress-strain curves.



(a) Cylinder 1.

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Figure 3.- Buckled cylinders.



(b) Cylinder 2.

L-64-2545

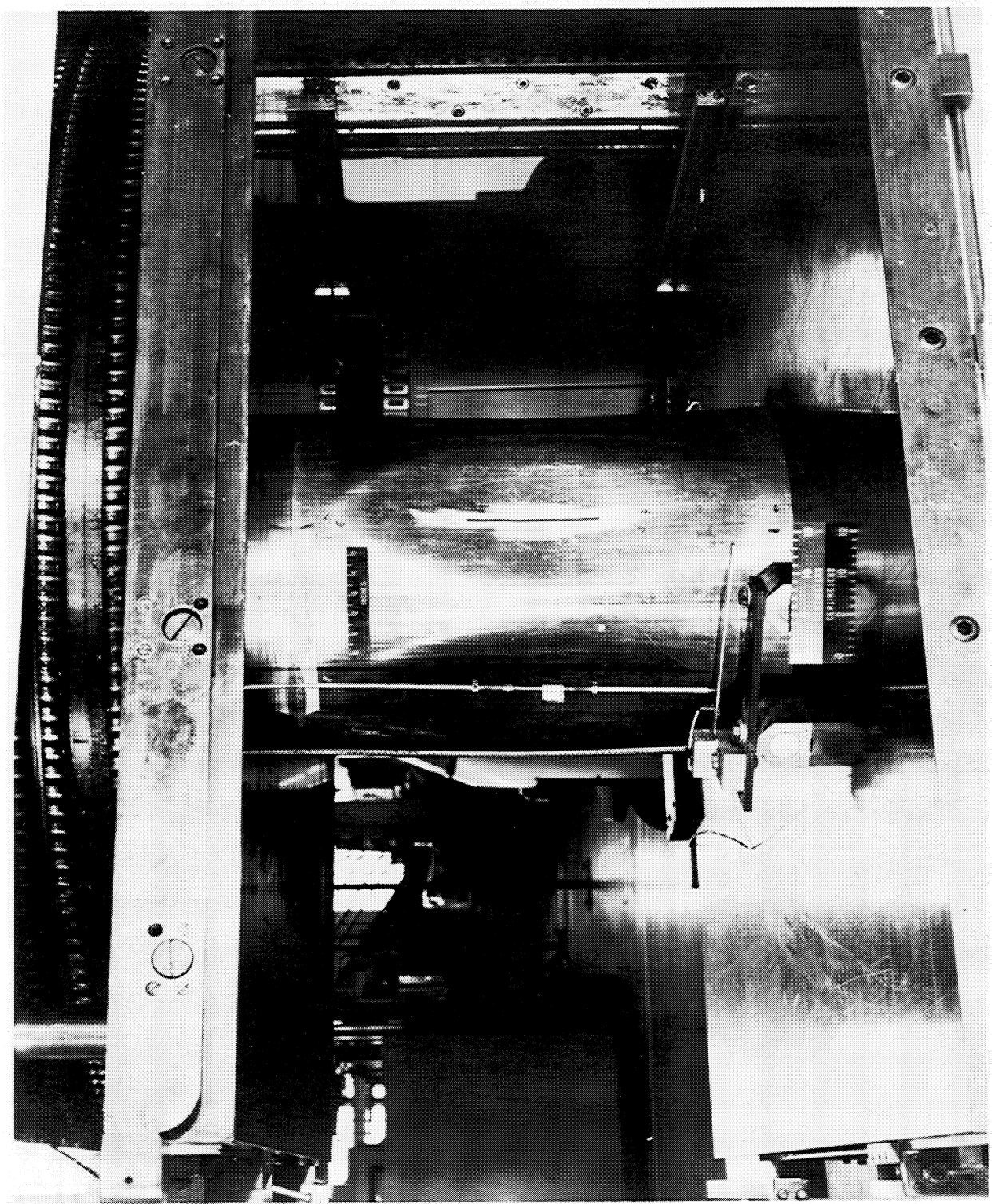
Figure 3.- Continued.



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(c) Cylinder 3.

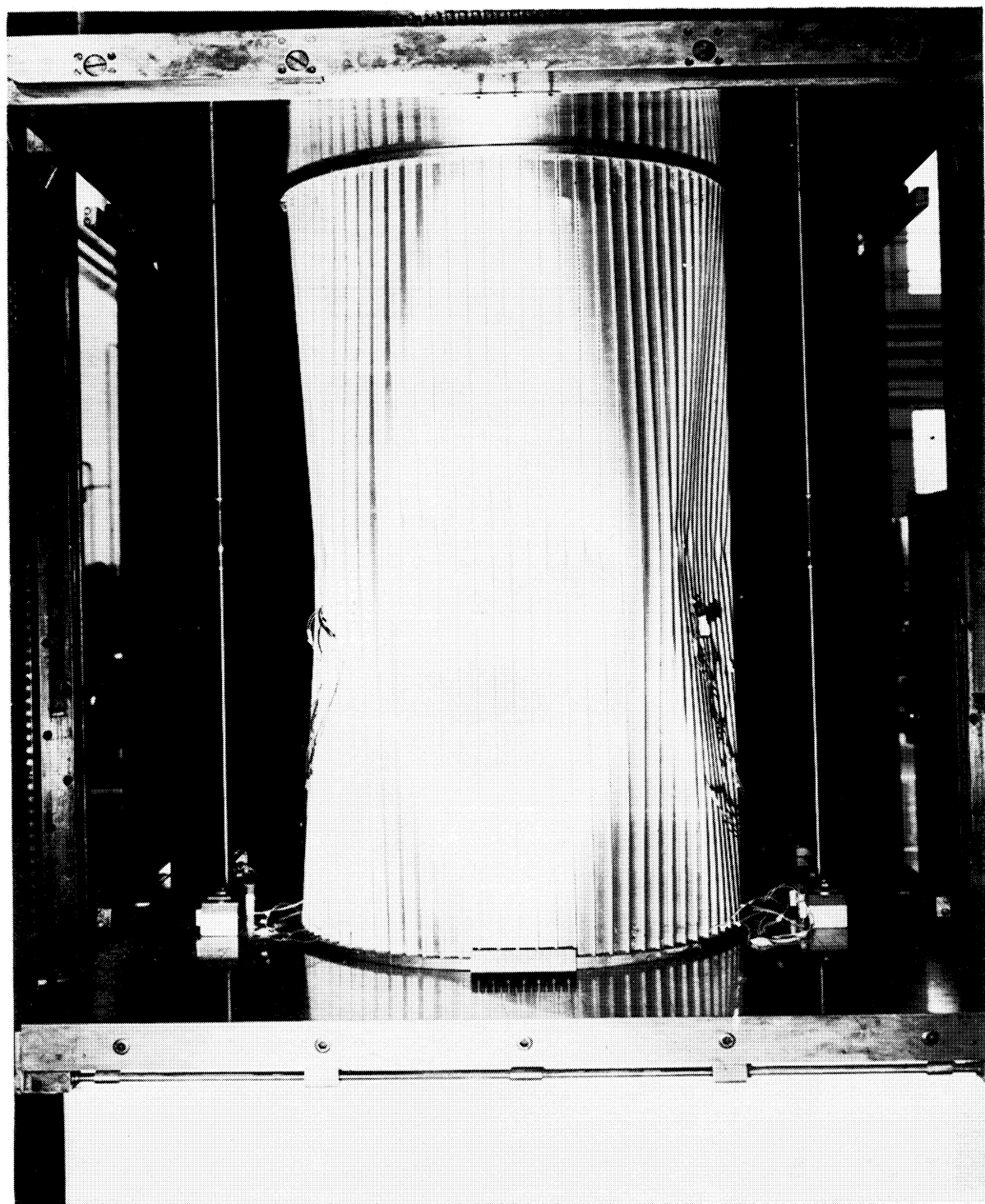
Figure 3.- Continued.



L-64-2546

(d) Cylinder 4.

Figure 3.- Continued.



(e) Cylinder 5.

L-63-3786

Figure 3.- Concluded.